The Development of the Ducted Fan Noise Propagation and Radiation Code CDUCT-LaRC

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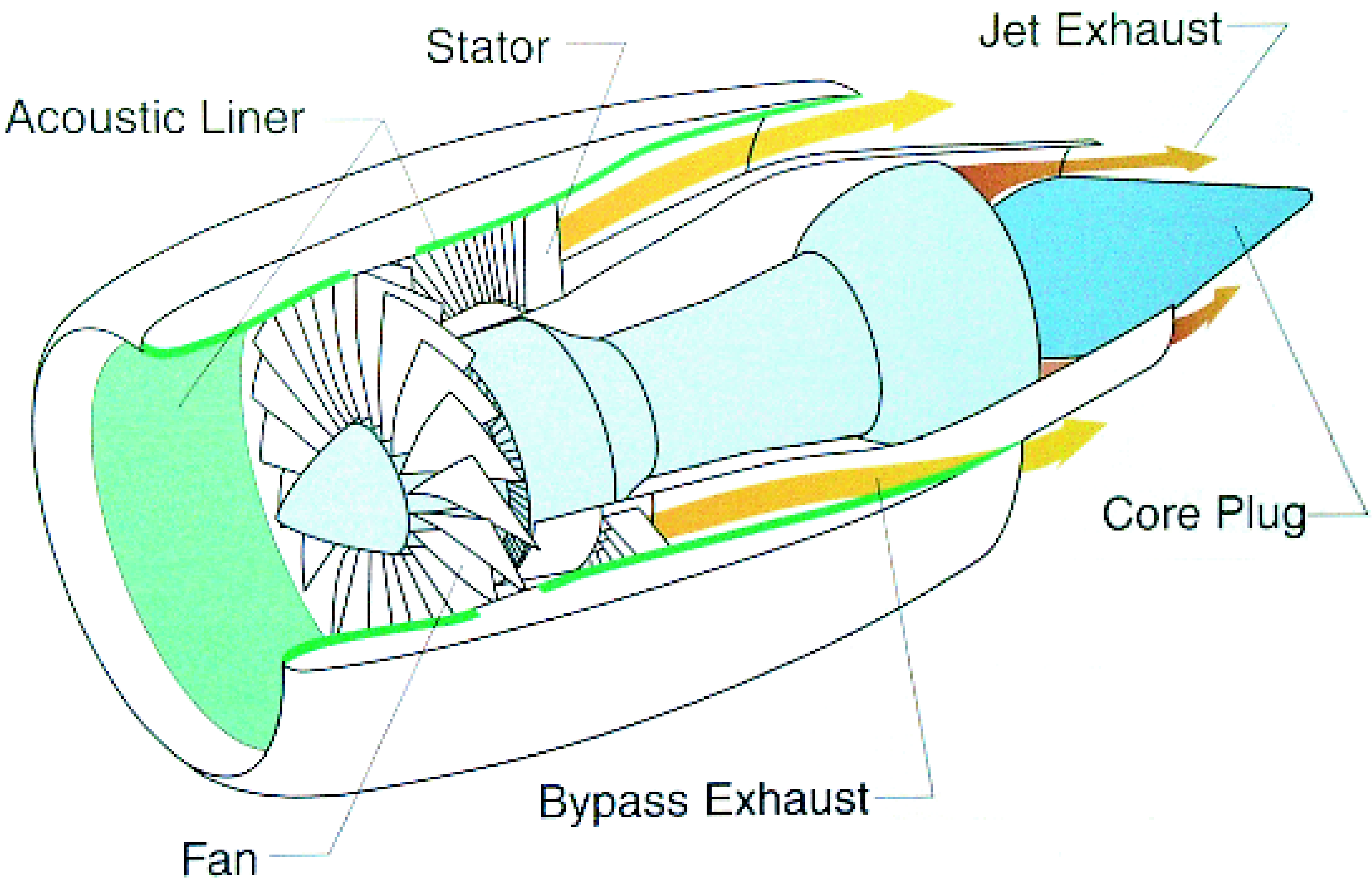
Introduction



Create a flexible and efficient environment in which to study propagation within and radiation from complex duct geometries

Outline

- Grid Generation Module
- Background Flow Module
- Duct Propagation Module
  - Boeing CDUCT Code Utilizing Parabolic Approximation

    (R.P. Dougherty, AIAA Paper 97-1652)

    (J. H. Lan, NASA CR-2001-211245)
- Acoustic Radiation Module
  - FW-H Equation with a Penetrable Data Surface

    (Brentner, Farassat, AIAA Journal, Vol. 36, No. 8)
- Preliminary Calculations
- Concluding Remarks

Grid Generation Module: Mean Flow

Approach :

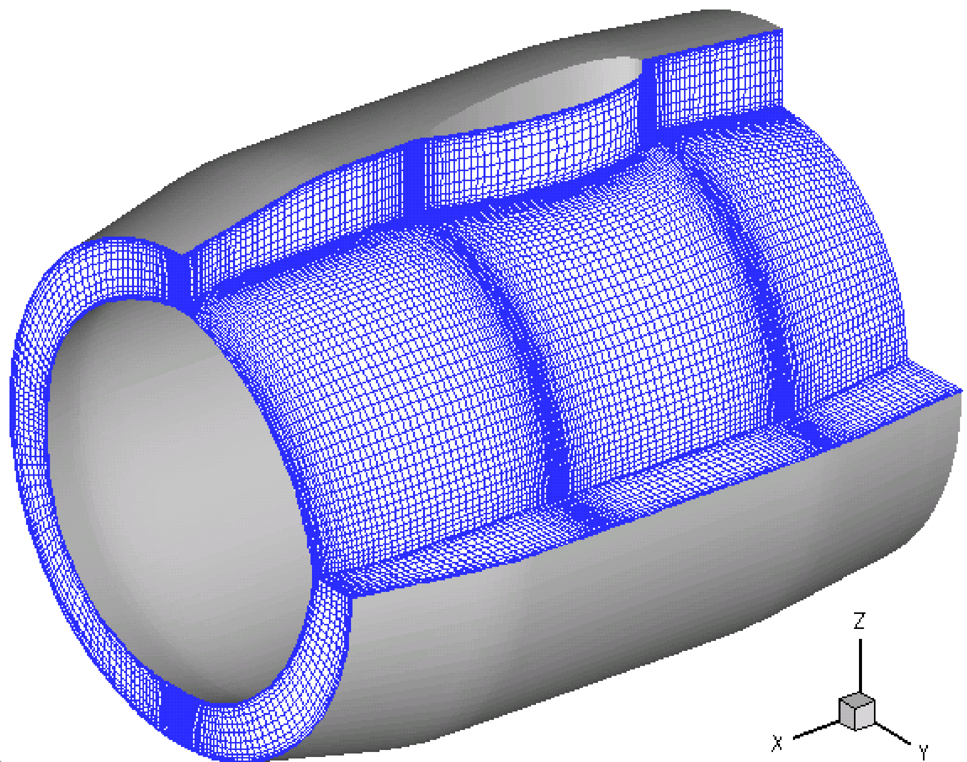
• Automatically generate a structured multi-block grid projected to NURBS (splined) surfaces created from user supplied surface geometry

Input :

• User specified as PLOT3D surfaces
  • Co-annular duct geometry
  • Pylon geometry (for aft radiation)
  • External nacelle surface geometry

Output :

• Structured multi-block grid in PLOT3D format suitable for mean flow calculations



Grid Generation Module: Propagation

Approach :

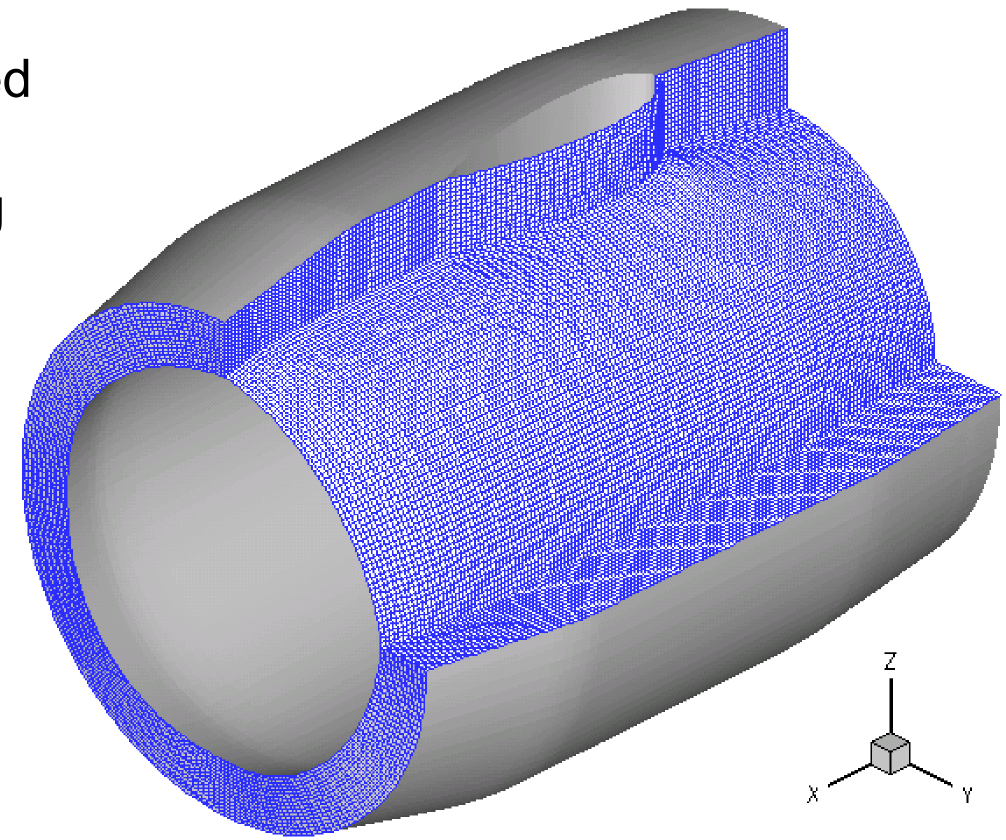
• Automatically generate a structured multi-block grid using NURBS volumes to facilitate redimensioning and redistribution

Input :

• Structured multi-block background flow grid in PLOT3D format

Output :

• Structured multi-block grid in PLOT3D format suitable for propagation calculations



Background Flow Module

Approach :

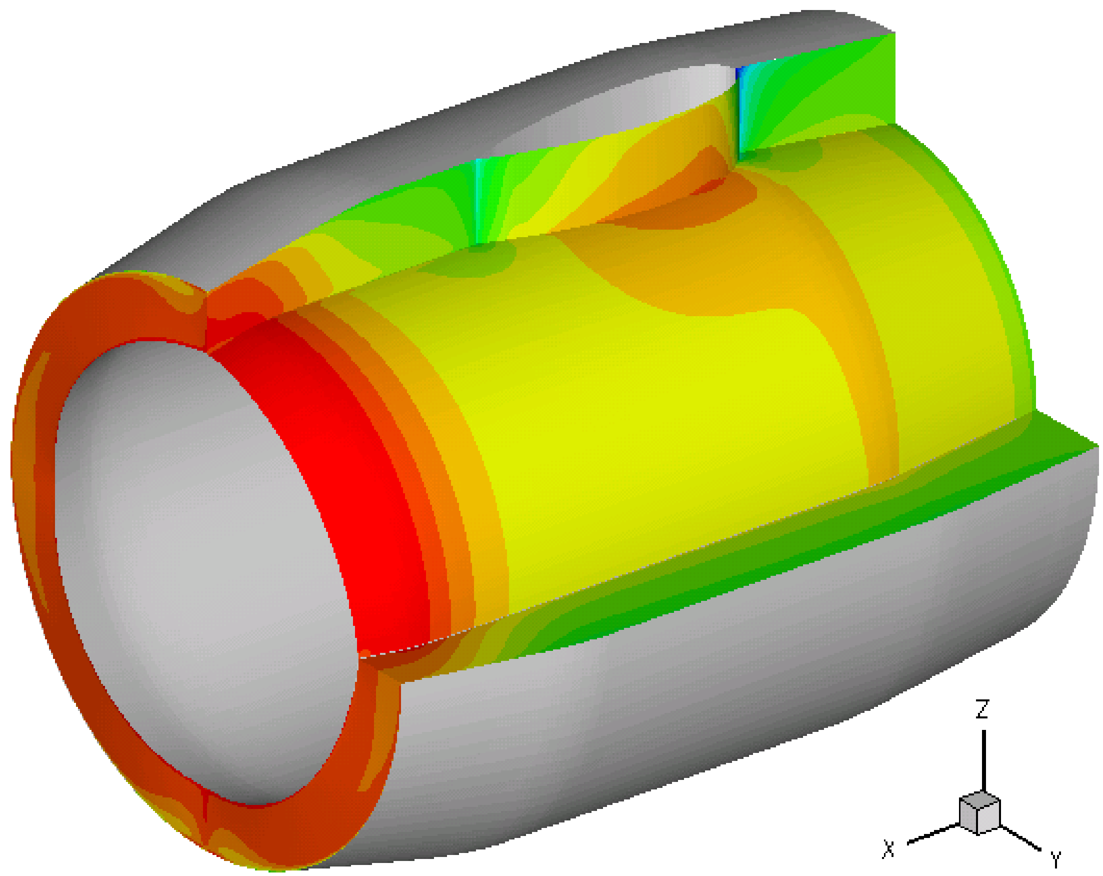
• Steady compressible inviscid CFD computation

Input :

• Structured multi-block grid in PLOT3D format
• Flow Conditions

Output :

• Mean flow quantities in PLOT3D solution file format



Duct Propagation Module

Approach :

• Existing model of Boeing CDUCT code based on parabolic approximation with no reflections. Dougherty (1997) - Lan(2001)

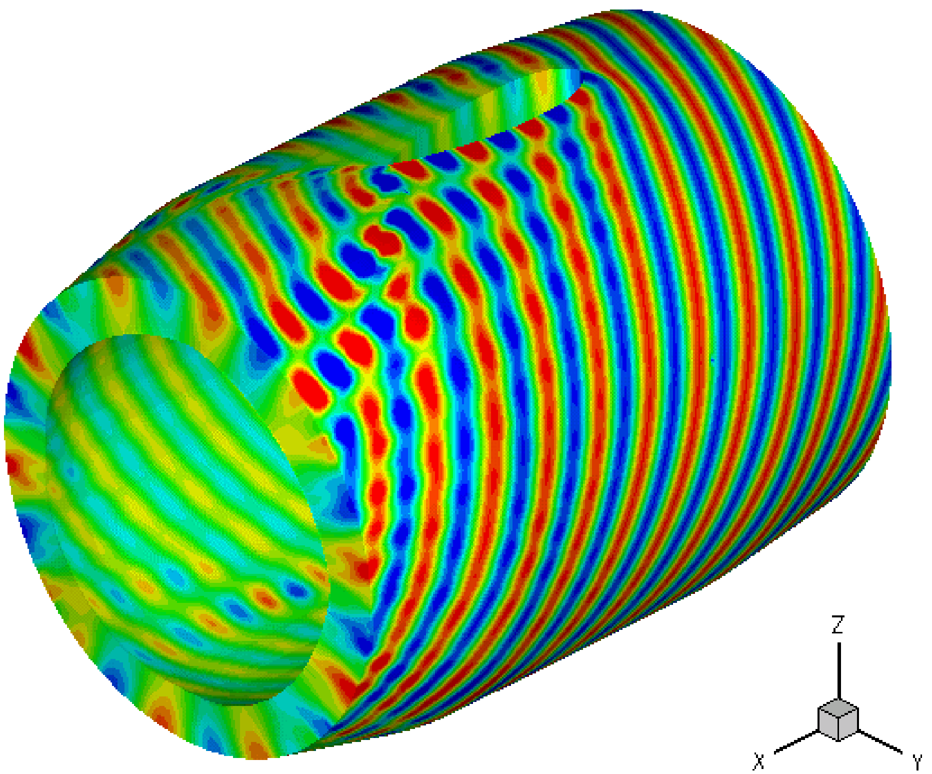
• Complex acoustic potential is calculated throughout each block.

Input :

• Mach number distribution from the mean flow calculations.

• Hardwall annular duct modes are specified in the inflow plane of the upstream block.

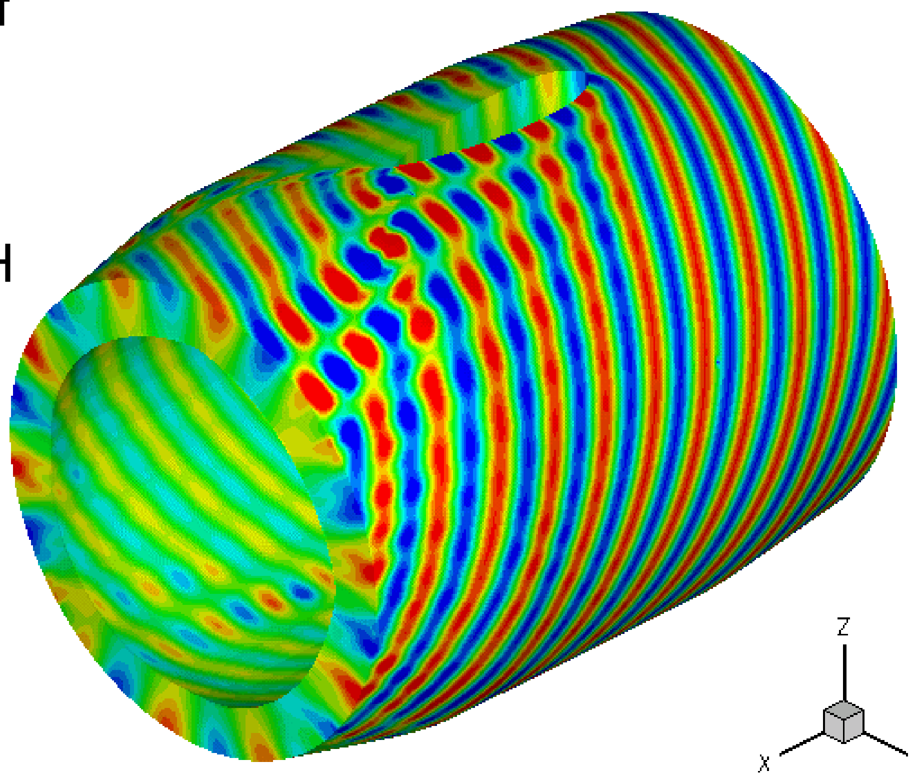
• Subsequent blocks are initialized using data from the exit surface of upstream blocks.



Duct Propagation Module

Output:

- Results may be output in the form of complex acoustic potential or pressure.
- Output of the complex acoustic potential is used in subsequent FW-H radiation calculations.



Current Activities :

- Hardwall annular duct modal input with the option to specify the energy in each mode at a fixed frequency.
- Specification of a pressure distribution (in a single plane) as input.

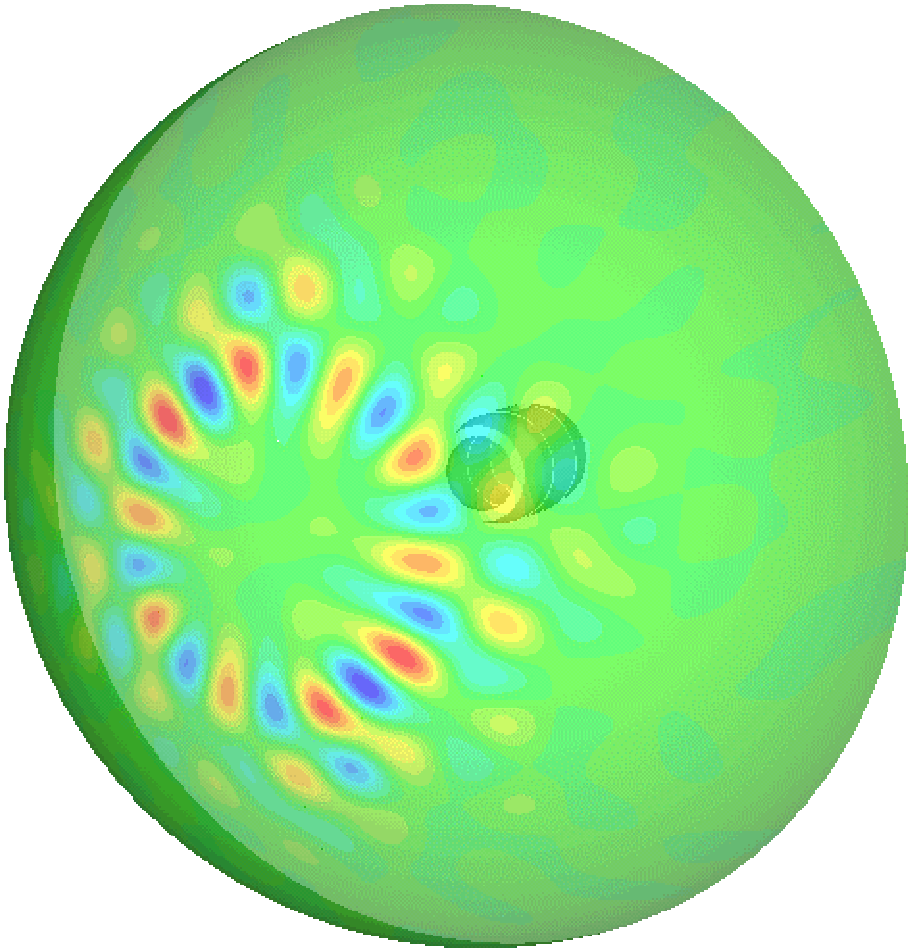
Acoustic Radiation Module

Approach :

- Ffowcs Williams-Hawkings equation with a penetrable data surface

Flow Data Input:

- Specified on the exhaust surface:
  - Mean flow quantities (ρ, **U**) from the background flow calculations
  - Acoustic quantities (ρ', p', **u**', $\nabla p'$, ∇**u**') from the complex acoustic potential obtained in the propagation calculations



Acoustic Radiation Module

The Development of CDUCT-LaRC

Observer Location Input:

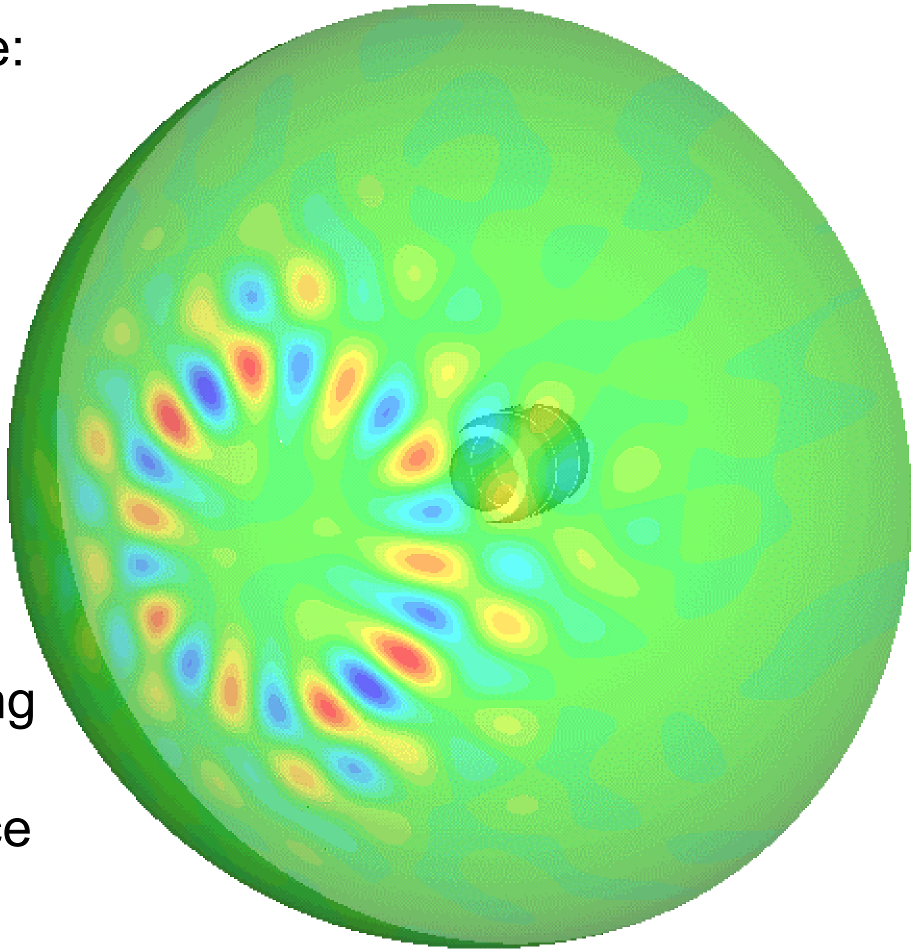
- Basic observer distributions available:
  - Sphere centered on the duct axis
  - Arc from the duct axis through *x* degrees
- User provided

Output:

- Radiated acoustic pressure

Current Activities:

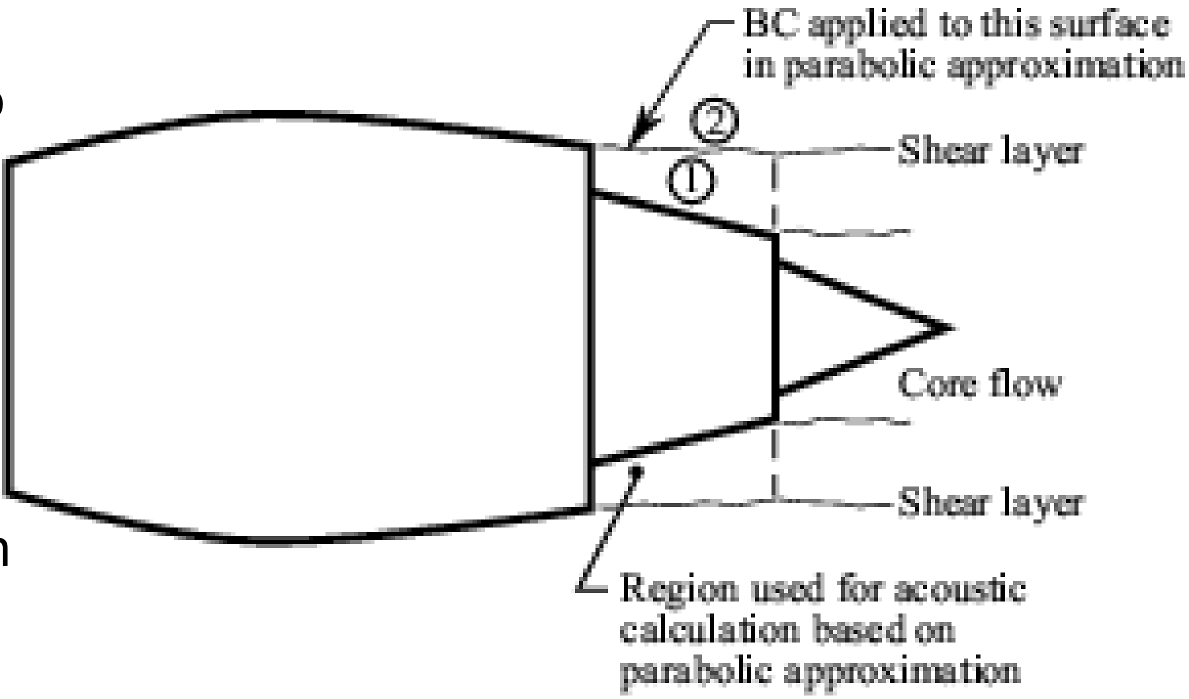
- Extension of the propagation calculations to a pseudo-duct extending beyond the exhaust or inlet plane
  - Account for presence of cowl surface
  - Account for refraction of sound through the shear layer



Acoustic Radiation Module

Approach:

- Extend the propagation calculation (using the parabolic approximation) to the shear layer region external to the duct.
- Find the normal velocity and pressure on the external surface of the shear layer.
- Apply FW-H equation with penetrable data surface to calculate far field radiation.
- This method will give the radiation in forward arc from the duct exhaust.



Preliminary Calculations

Three ducts have been initially tested:

- Duct 1: straight co-annular duct having inner and outer radii 0.285 m (11.23 in) and 0.412 m (16.22 in), respectively. The duct length is 1.07 m (42.88 in).
- Duct 2: similar to duct 1 except that infinitely thin pylons are placed in the top and bottom of the middle third of the duct.
- Duct 3: bypass duct of a small business jet with dimensions similar to duct 1. The pylon is modeled as a NACA 0015 airfoil.

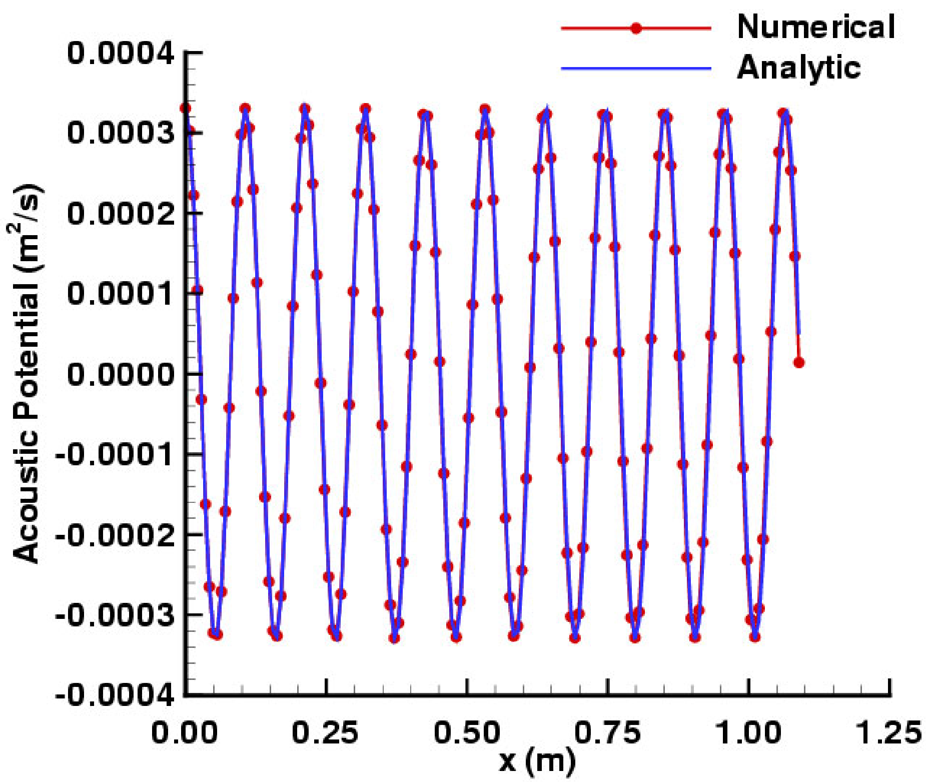
Configurations similar to ducts 2 and 3 may include only a single pylon.

Preliminary Calculations

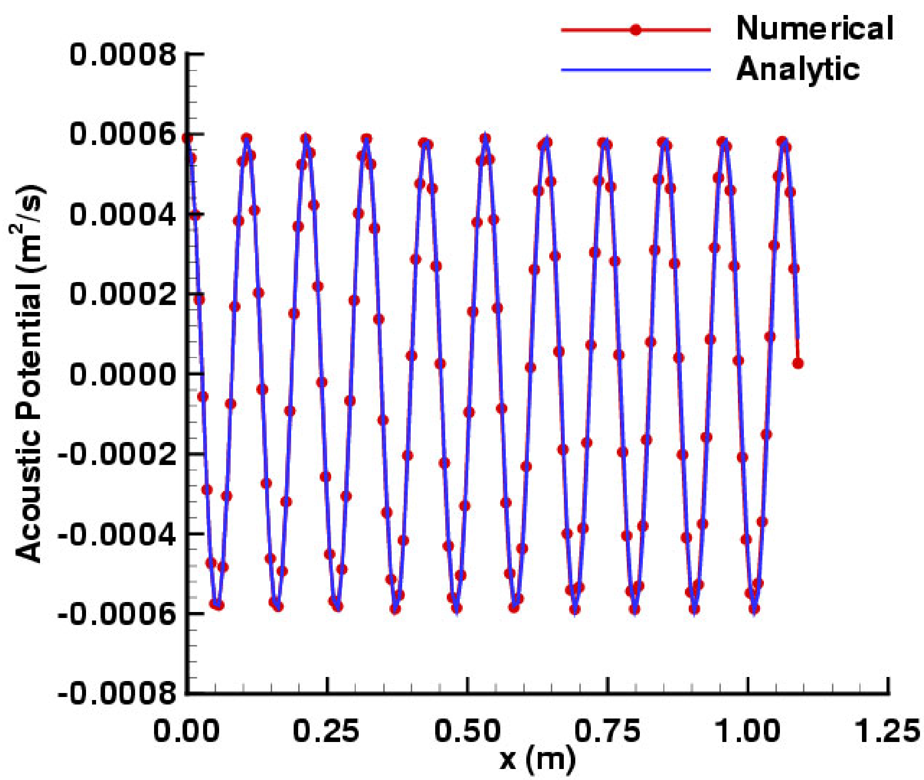
Comparison of CDUCT-LaRC Propagation Calculation and Analytical Results along a line parallel to duct axis – Downstream Propagation

Mode (10,1), M=0.4

r = 0.308 m (12.1 in)



r = 0.377 m (14.8 in)

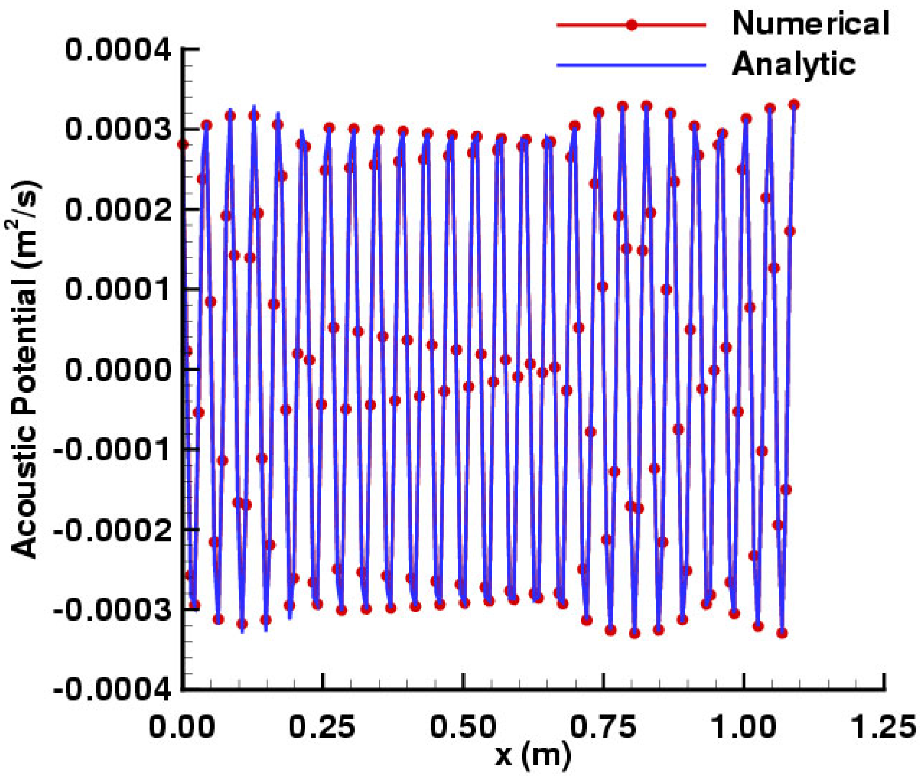


Preliminary Calculations

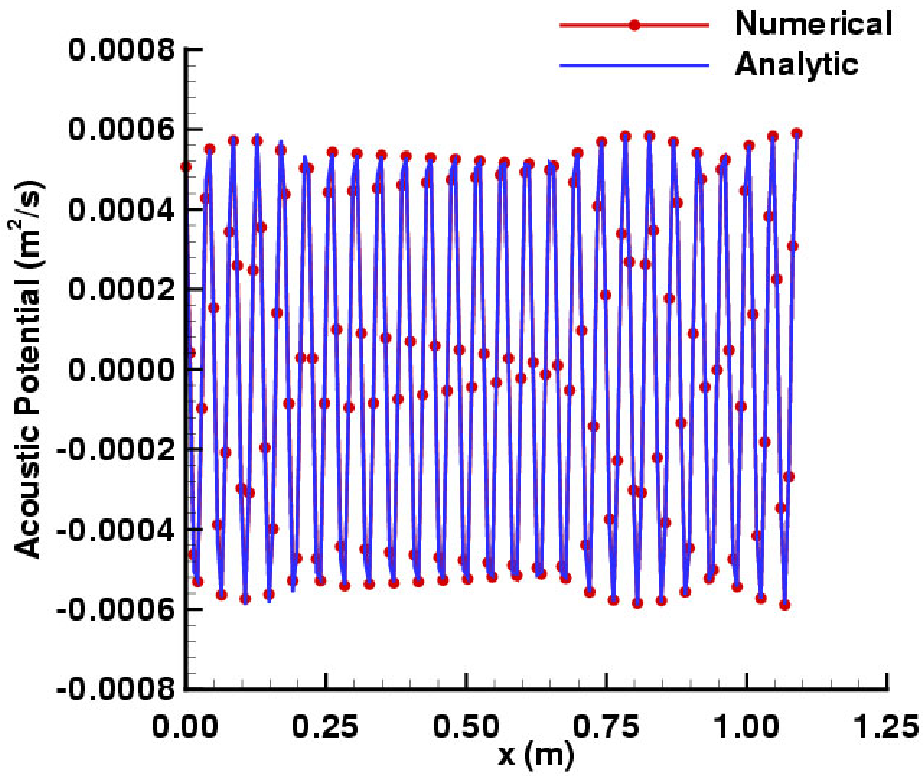
Comparison of CDUCT-LaRC Propagation Calculation and Analytical Results along a line parallel to duct axis – Upstream Propagation

Mode (10,1), M=0.4

r = 0.308 m (12.1 in)

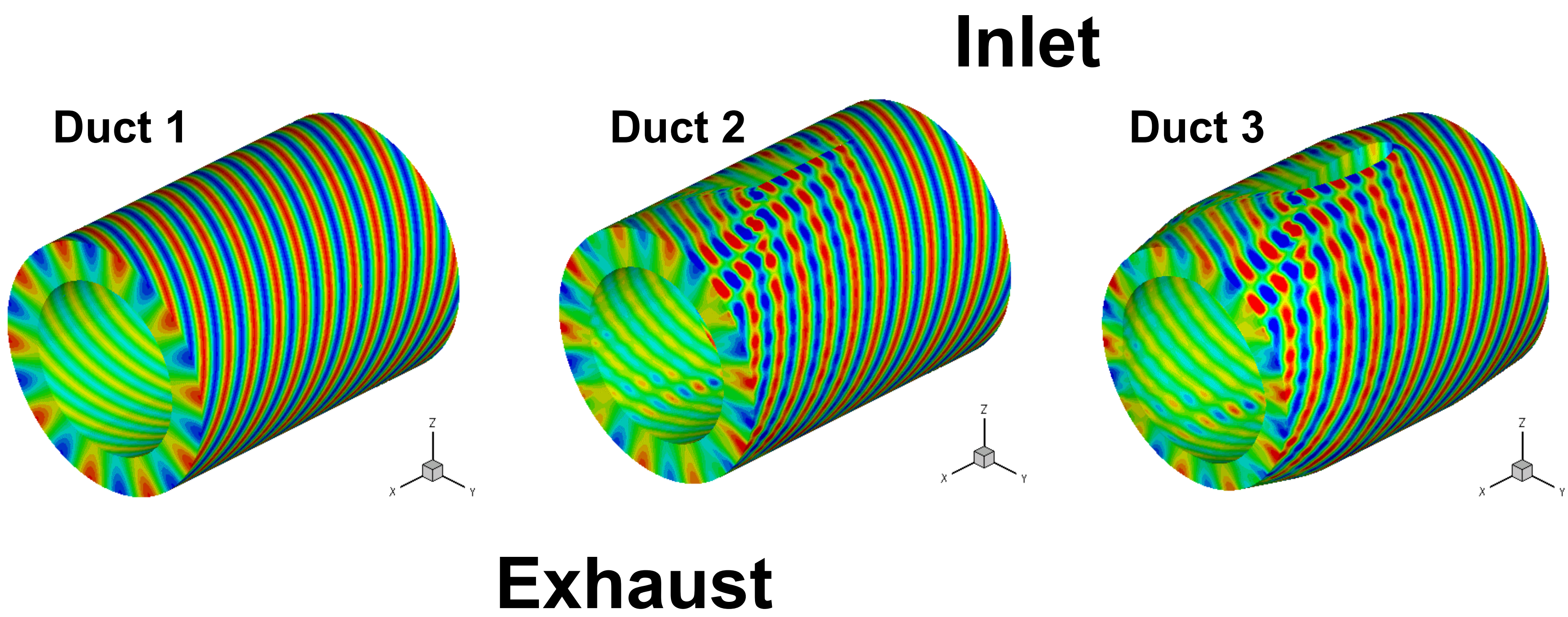


r = 0.377 m (14.8 in)



Preliminary Calculations

Real Part of Acoustic Potential – Mode (10, 1)
Inlet Mach Number 0.4, Frequency 5000 Hz

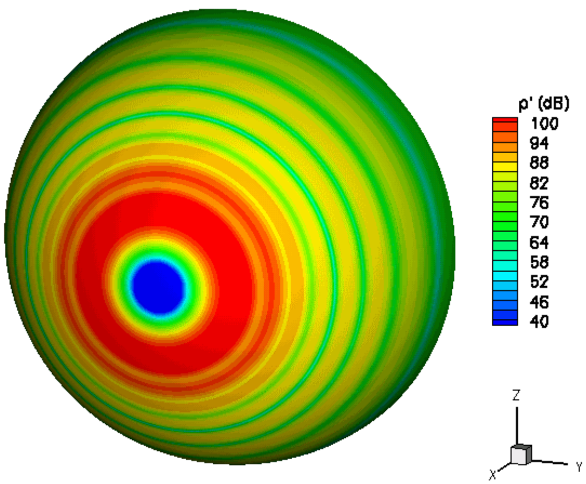


Preliminary Calculations

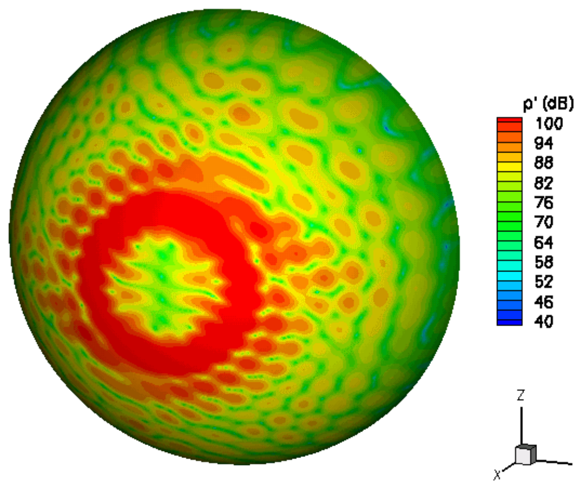
Radiated Sound Pressure Level – Mode (10, 1)
Inlet Mach Number 0.4, Frequency 5000 Hz

Sphere of radius 5 duct diameters centered on the duct axis in the exhaust plane

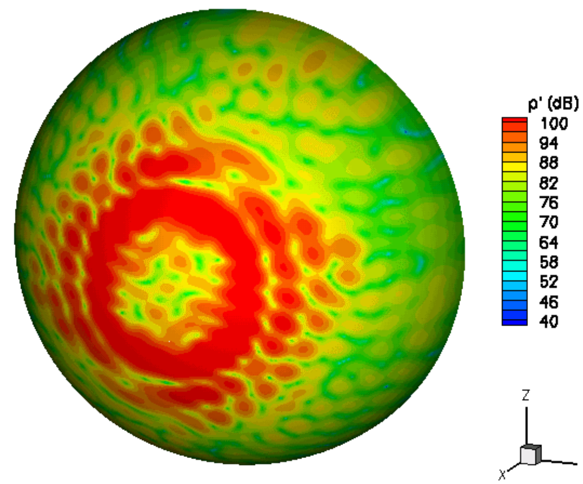
Duct 1



Duct 2



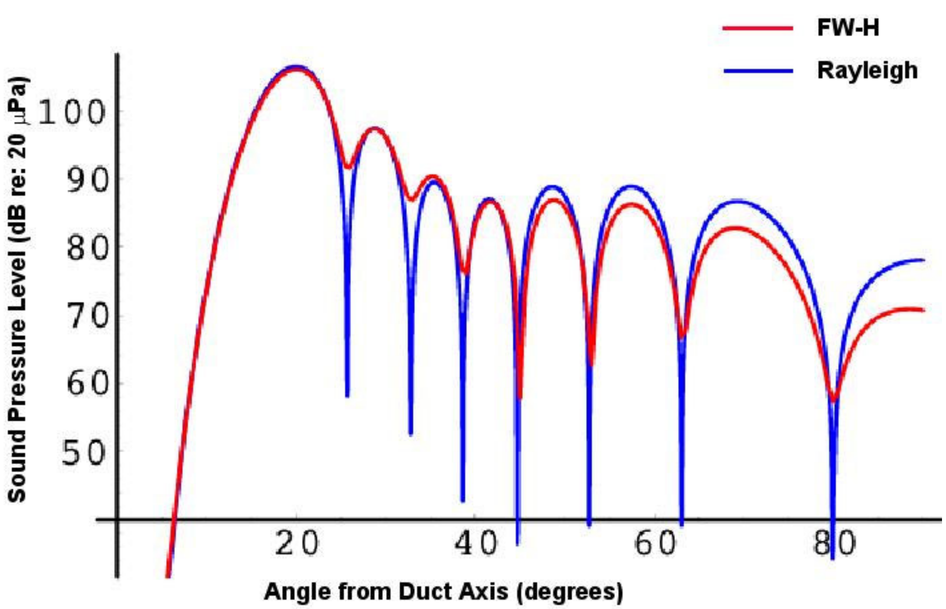
Duct 3



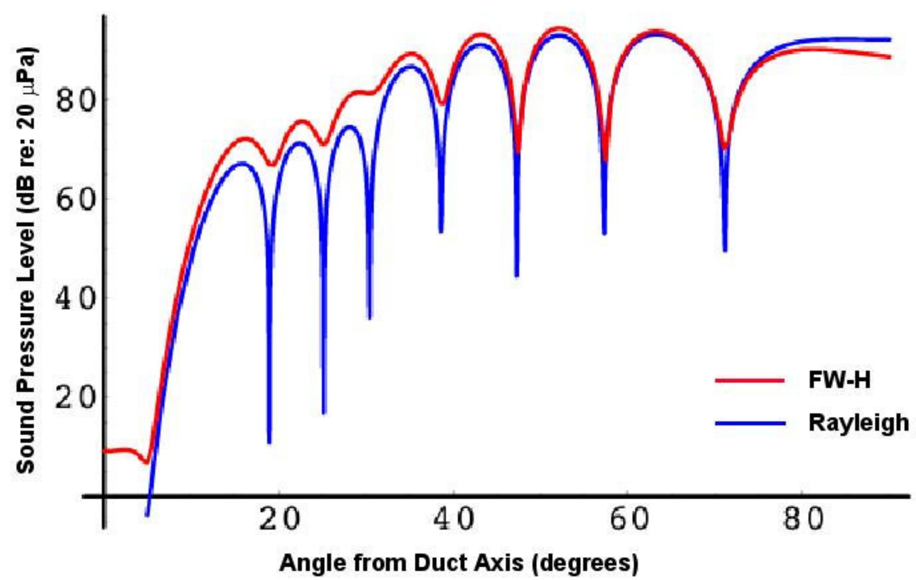
Preliminary Calculations

Comparison of CDUCT-LaRC (FW-H) and Rayleigh (Analytical) Radiation Calculations: Duct 1

(10, 1) Mode
Cut-Off Ratio 3.59



(10, 4) Mode
Cut-Off Ratio 1.26



Liner Specification

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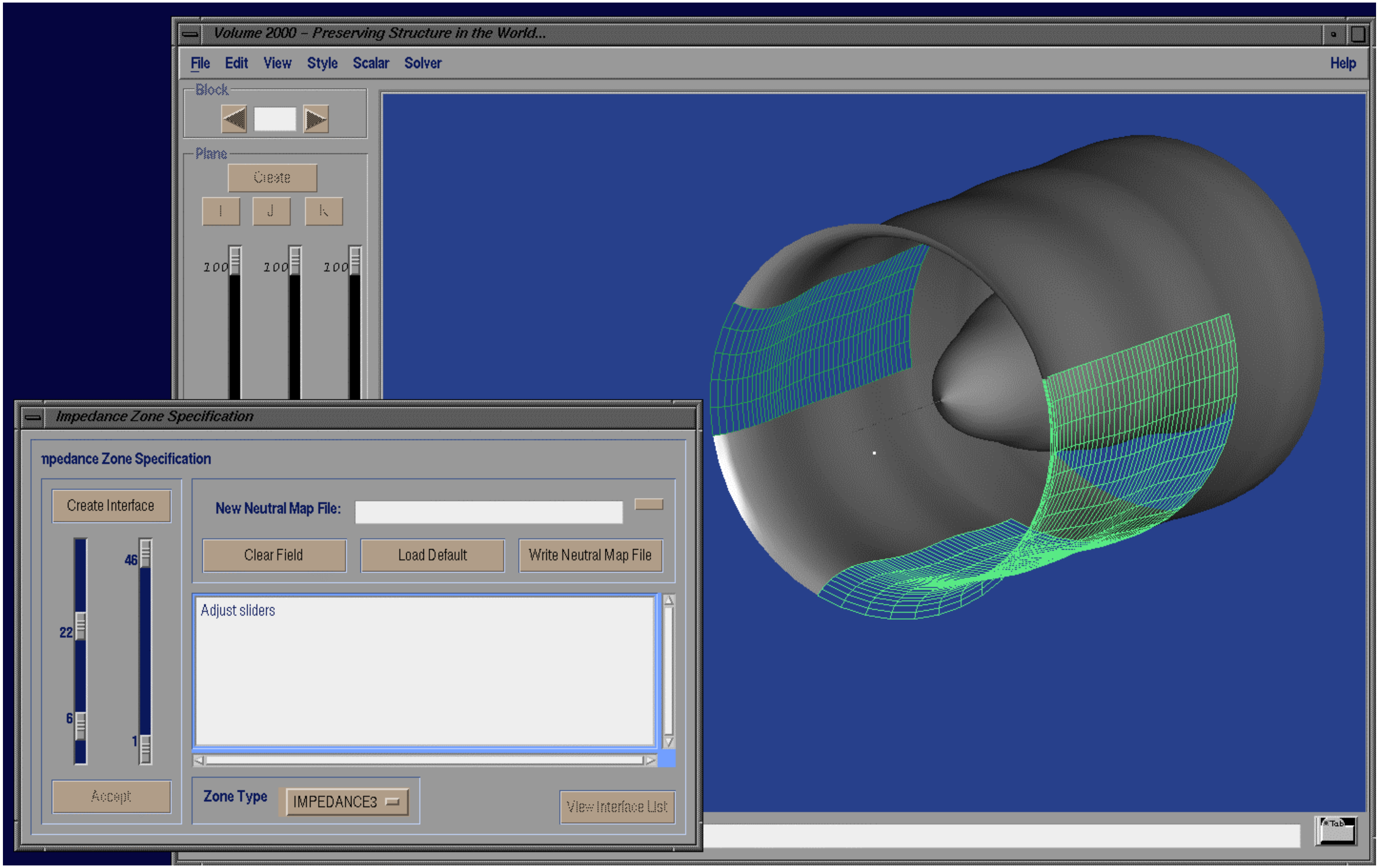

Concluding Remarks

- Validation is underway and will include :
  - Large range of frequencies and modes
  - Various engine inlet and exhaust geometries
  - Various liner configurations, axially and radially segmented

- Preliminary results indicate that the modules for duct propagation and radiation offer appropriate physical models for noise prediction

- A focused study of pylon geometry with liner may identify a new approach for engine noise control